Comment on "Search for nonresonant capture in the $^{16}O(\alpha,\gamma)^{20}Ne$ reaction at low energies"

D. Baye and P. Descouvemont
Physique Théorique et Mathématique CP229, Université Libre de Bruxelles, Brussels, Belgium
(Received 11 December 1987)

The recent results of Hahn *et al.* on the $^{16}O(\alpha,\gamma)^{20}Ne$ capture reaction are discussed in the light of a microscopic calculation. We suggest that the S factor at 300 keV proposed by Hahn *et al.* should be substantially increased.

In a recent paper,[1] Hahn *et al.* presented new experimental results on the $^{16}O(\alpha,\gamma)^{20}Ne$ capture reaction at low energies, including the first off-resonance data. This reaction is very important for testing microscopic models of α capture by light heavy ions: For closed-shell nuclei, the basic assumptions of these models are simple and reliable and a disagreement with experiment would have far-reaching consequences. However, the $^{16}O(\alpha,\gamma)^{20}Ne$ cross section has not been measured until now, since this reaction plays a minor role in stellar evolution.[2] In this Comment, we aim to show that the data at the lowest energy are in fair agreement with our calculation,[3] while the energy behavior of the off-resonance data might be in contradiction with theory. In addition, we suggest that the extrapolated 300 keV S factor proposed in Ref. 1 is most likely to small. Before discussing the data, we briefly summarize the present status of theoretical descriptions of the $^{16}O(\alpha,\gamma)^{20}Ne$ reaction.

The $E2$ component of the $^{16}O(\alpha,\gamma)^{20}Ne$ capture reaction is studied microscopically in Refs. 3 and 4. In a microscopic model antisymmetrization and good quantum numbers are treated exactly. The twenty-nucleon Schrödinger equation is solved by assuming a harmonic-oscillator closed-shell structure for the α and ^{16}O nuclei. The ^{20}Ne states are described by an $\alpha+{}^{16}O$ cluster configuration. This model reproduces the ^{20}Ne bound states and narrow resonances of the 0_1^+ and 0^- bands, and the broad resonances of the 0_4^+ band. However, it does not provide the 0_2^+ resonance at 6.73 MeV excitation energy, which lies in the energy range studied in Ref. 1. The 0_2^+ state is believed to have a dominant $\alpha+{}^{16}O^*$ component.[5] The $B(E2)$ in the 0_1^+ and 0^- bands are fairly well reproduced by the model. The $E2$ capture essentially arises from the s wave (because of its lower Coulomb barrier) to the 2^+ excited state of ^{20}Ne. The corresponding S factor is denoted in the following as S_2. The S factor S_0 for capture to the ground state and the total S factor obtained in Refs. 3 and 4 are displayed in Fig. 1. We have also studied the "forbidden" $E1$ component of the cross section by adding a second channel involving isospin impurities.[6] This component is found rather small ($\sim 10\%$) and can be disregarded at the level of accuracy of the following discussion.

The same reaction has been studied with the orthogonality condition model (OCM), a semimicroscopic model[7] (i.e., involving an approximate Schrödinger equation for the relative motion). Some discrepancies between the microscopic and semimicroscopic results led us to perform a detailed comparison of both models[4] with the following results for the $^{16}O(\alpha,\gamma)^{20}Ne$ reaction: (i) The OCM leads to an overestimation by about 40% of the low-energy S factor with respect to the generator coordinate method (GCM) calculation, and (ii) both models provide the *same energy dependence,* i.e., the S factor increases slightly with decreasing energies. The larger results of Ref. 7 are therefore due to the OCM approximation while, below 1 MeV, the S factor decrease with decreasing energies (see the dashed curve in Fig. 1) is due to an insufficiently accurate treatment of the wave functions at large interdistances (see Fig. 8 and its discussion in Ref. 4).

The comparison between the cross sections measured by Hahn *et al.* and those calculated theoretically is rendered difficult by the lack in the models of the 0_2^+ resonance located 1.99 MeV above the threshold. This problem is avoided for the ground-state S factor on which Hahn *et al.* focus their comparison with theory. First, let us rather consider the experimental total S factor at the three off-resonance energies. Of course, even at these energies, a non-negligible resonant contribution from the 0_2^+ and 3_2^- states is expected, but a meaningful comparison with theory is possible anyhow. The total S factor S_0+S_2 at 1.7, 2.3, and 2.35 MeV is represented by vertical bars in Fig. 1 and should be compared with the upper full curve. The 1.7 MeV point is in good agreement with the microscopic results if one assumes about 50% of resonant contribution as suggested by Fig. 6 of Ref. 1. However, the results near 2.3 MeV are much smaller than the theoretical prediction in spite of the fact that the experimental data include a significant contribution of the 0_2^+ and 3_2^- resonances, which is lacking in the theoretical value. Moreover, the total S factor (see Fig. 1) seems to show a strong energy dependence between 1.7 and 2.3 MeV. The experimental value at 1.7 MeV is larger by about a factor of 3 than the values at 2.3 and 2.35 MeV, whereas the resonant contribution to S_0+S_2 should not be more important at 1.7 MeV (see Fig. 6 of Ref. 1). As stated in Ref. 1, at the 95% confidence level, the experimental results are not inconsistent with an energy-independent nonresonant total S factor as large as 2.3 MeV b if one assumes a fully destructive interference above the 0_2^+ resonance. However, the S factor towards the ground state presents (at the $1-\sigma$ level) a correlated decrease which cannot be explained by an s-wave interference. The rather large error bars forbid definite conclusions, but the simultaneous decrease of S_0 and S_0+S_2, observed at two energies, is puzzling. Although the data are not inconsistent with an energy-independent S factor, we think that the 2.3 and 2.35 MeV results should receive a lower weight in the averaging process.

For ground-state capture, the 1.7 and 2.2 MeV data points agree very well with our microscopic results. The OCM results (dashed line) overestimate the S factor, as expected from the discussion in Ref. 4. The two data points may indicate that our theoretical cross section is slightly larger than the experimental one. Single-channel microscopic calculations often overestimate the capture cross section, but the closed-shell character of the fusing nuclei should make this effect rather weak in the present case. If we start from the average value of the 1.7 and 2.2 MeV points ($\sim$0.4 MeV b) and multiply it by the theoretical $(S_0+S_2)/S_0$ factor ($\sim$4.3), the resulting extrapolated S_0+S_2 at low energies is then about 1.7 MeV b. Of course, it is not possible to establish a level of accuracy for this extrapolation. We think that the value 0.7$\pm$0.3 MeV b proposed in Ref. 1 is an underestimation because it is based on rather conservative assumptions. The authors take account, with equal weight, of three very close points exhibiting an unrealistic energy dependence and extrapolate with the incorrect energy behavior of Ref. 7. With the four-point average $S_0=0.26\pm0.07$ MeV b employed in Ref. 1 but with our branching ratio and energy dependence, we would already obtain $S_0+S_2\approx1.1\pm0.3$ MeV b, a value which in our opinion is probably still too small.

In summary, the results of Hahn *et al.* agree nicely with the fully microscopic approach at 1.7 and 2.2 MeV. The 2.3 and 2.35 MeV results are, on the contrary, very puzzling and deserve further experimental attention. On the theoretical side, microscopic calculations should try to consistently include the influence of the 0_2^+ state. The nonresonant S factor presented in Ref. 1 might be underestimated because of the 2.3 and 2.35 MeV data. The extrapolation presented in Ref. 1 is also biased by inaccuracies in the OCM calculation. We think that the 300 keV S factor recommended by Hahn *et al.* should at least be multiplied by a factor of 2.

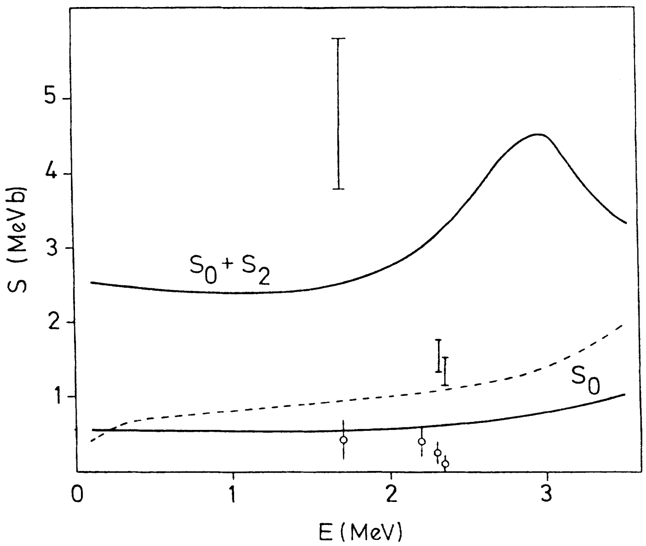

FIG. 1. $^{16}O(\alpha,\gamma)^{20}Ne$ total S factor (S_0+S_2) and S factor for capture to the ground state (S_0). The full curves are the microscopic results of Refs. 3 and 4, and the dashed curve is the OCM calculation of Ref. 7 for the ground-state contribution. The experimental data (Ref. 1) are represented by vertical bars (total S factor) and by circles (ground-state contribution).

This work was partly supported by the Fonds National de la Recherche Scientifique.

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